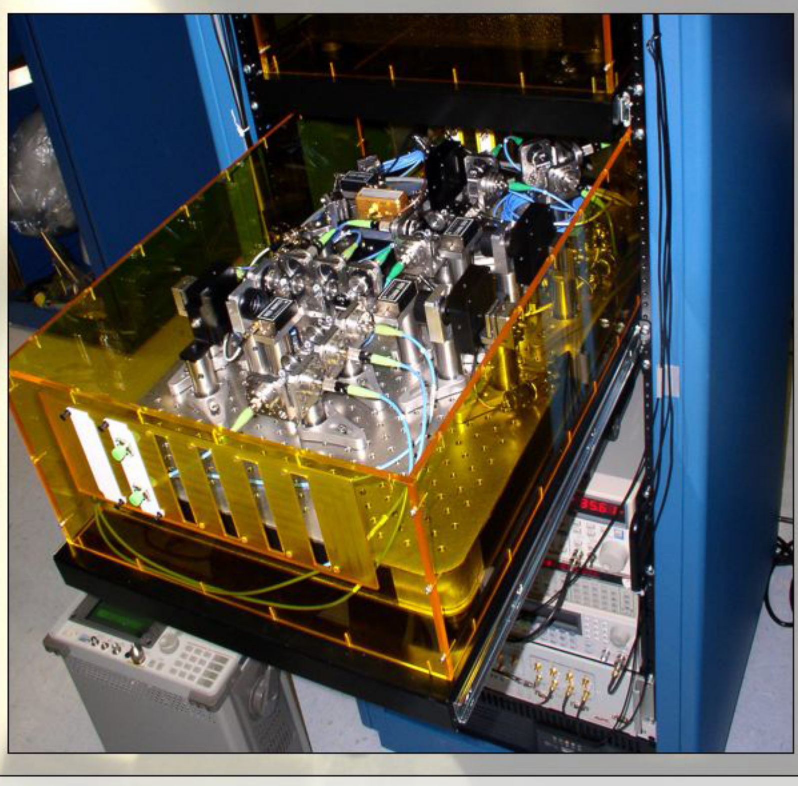
Initial Evaluation of the USNO Rubidium Fountain

S. Peil, S. Crane, T. Swanson and C. R. Ekstrom
United States Naval Observatory
Washington, DC 20392
http://tycho.usno.navy.mil/clockdev/CDpapers.html

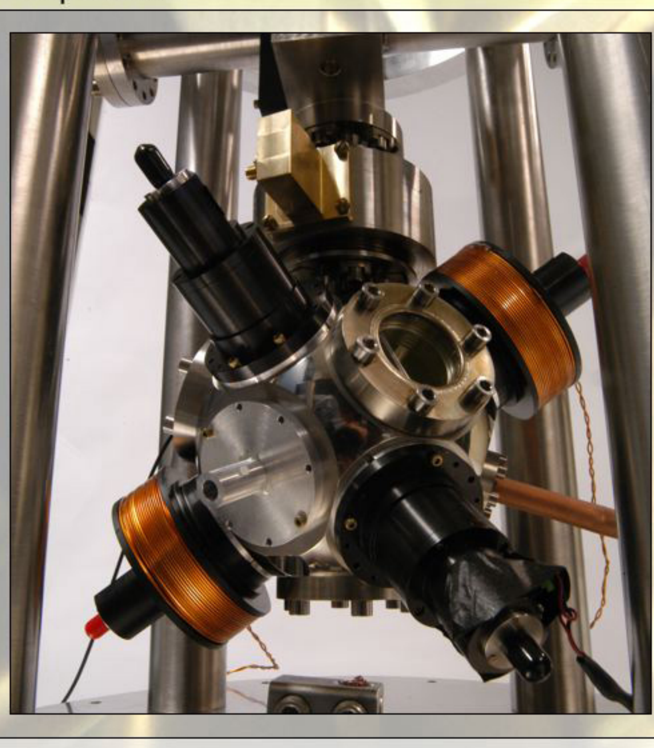
Fountain Design

Abstract - We present initial evaluations of our recently assembled rubidium atomic fountain - the first of six that are designed for continuous operation and for inclusion into the USNO timescale. We have measured short-term performance in weak-gradient, MOT-loaded operation as a good as $1.35\times10^{-13}/\tau^{1/2}$.

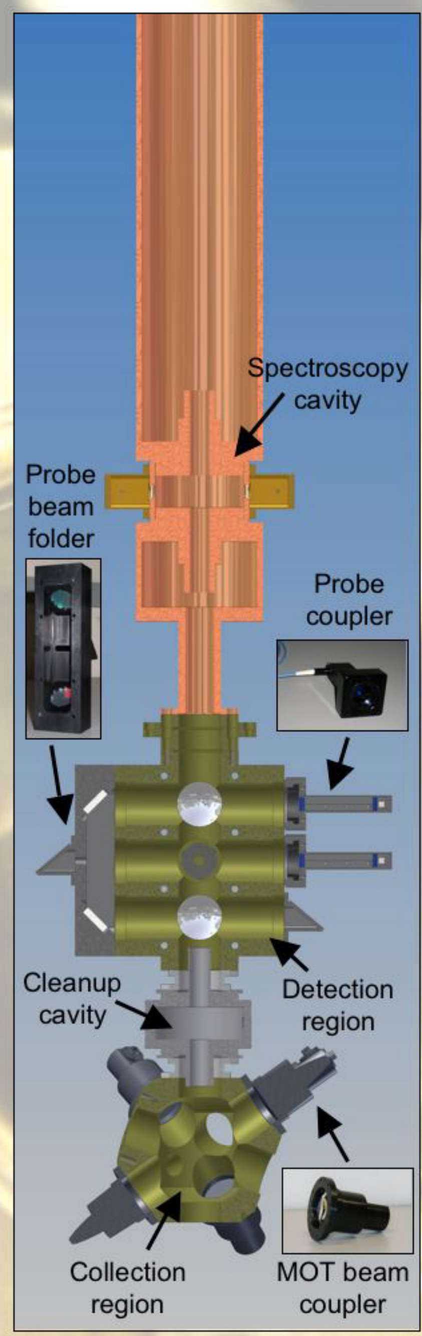
We have begun comparisons between our rubidium fountain (NRF1) and cesium fountain (NCF), demonstrating relative stability limited by white-frequency noise down to an Allan deviation of 1.5×10^{-15}. Assuming that each fountain exhibits the same noise type, the data are consistent with an Allan deviation for our rubidium fountain of 7×10^{-16} at 11 hours. Further upgrades to our cesium fountain should enable more precise comparisons.



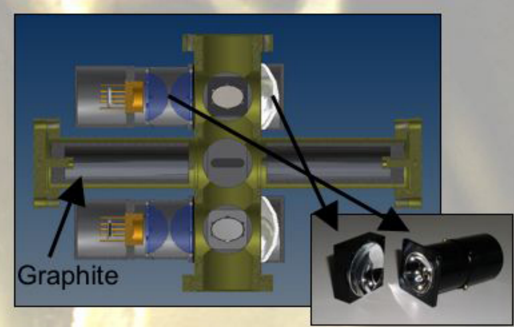
Our fountains are required to run in an operational environment without user intervention. Toward this end we have developed a compact, robust system that is contained in three equipment racks. Shown here is our rack-mounted miniature optical table with which all of the laser beam-splitting and frequency-shifting is carried out. Optical fibers transmit laser light from this table to monolithic couplers at the physics package.



The physics package consists of machined titanium vacuum chambers with weld-in windows. Monolithic couplers which bolt directly to the vacuum chamber deliver the required collection/launching, detection and probe laser beams. All components are nonmagnetic.



Rb atoms (~10^8 atoms in MOT or 5×10^6 in molasses) are collected, cooled and launched with a velocity of 4 m/s every 1.2 s from the collection region. A moving-frame molasses duration of 1.6 ms and adiabatic beam turnoff of 0.2 ms cools the atoms to ~1.5 μK. A cleanup microwave cavity and laser beams in the detection chamber prepare the atoms in the $|1,0\rangle$ state for Ramsey spectroscopy. As the atoms fall back down, collection optics (F/0.64 lenses and spherical mirror) capture the light scattered by returning atoms.

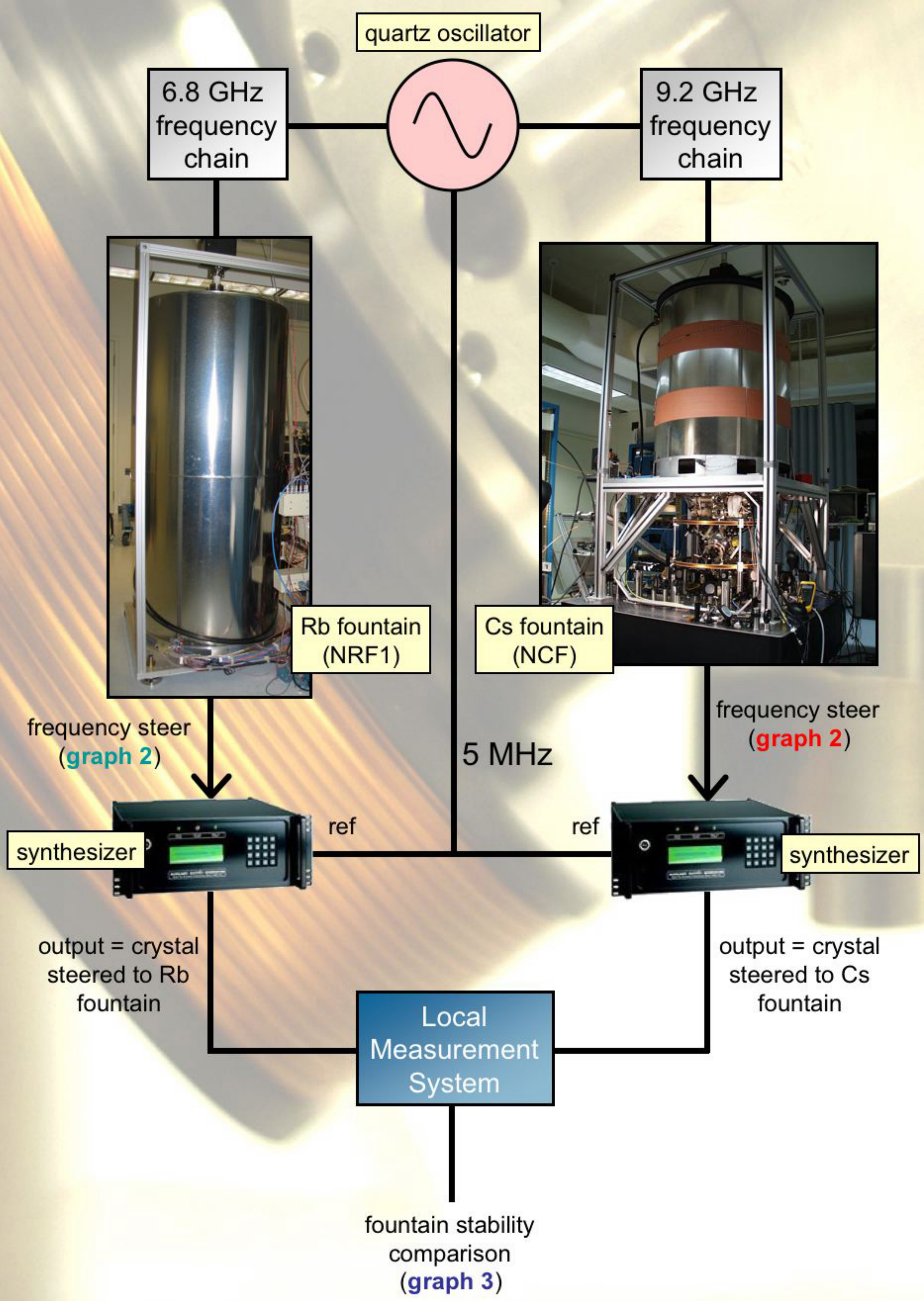


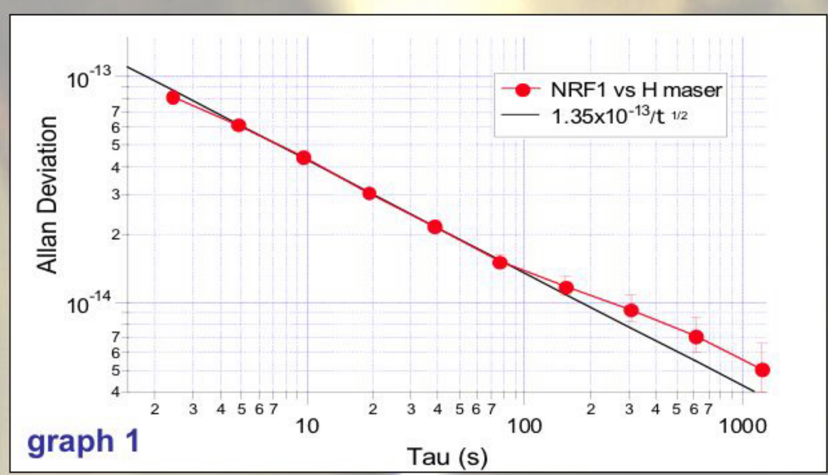
Detection region, side view.

Collection optics

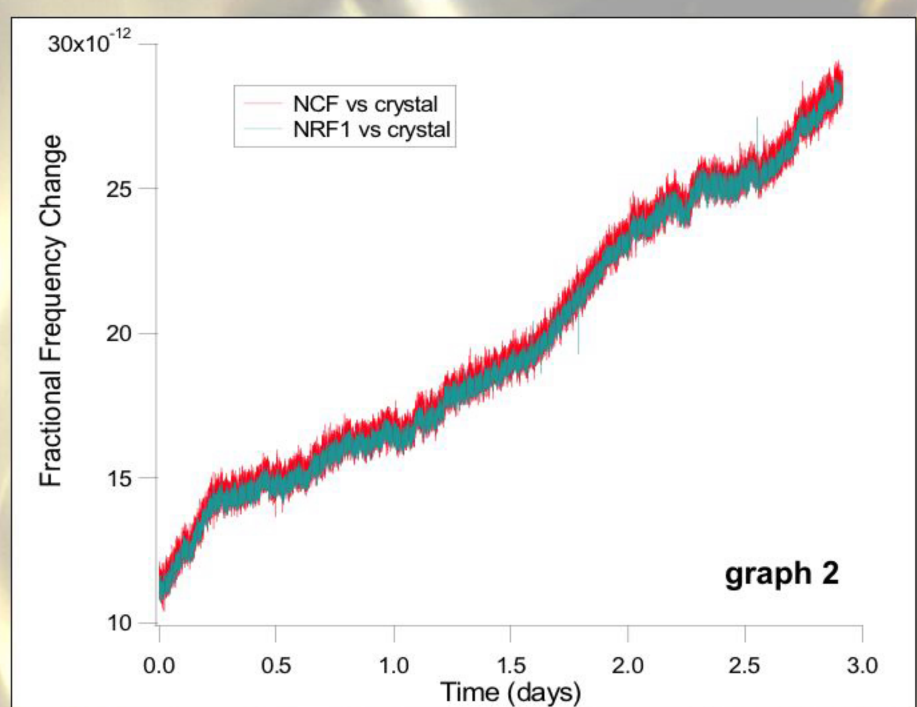
Characterization

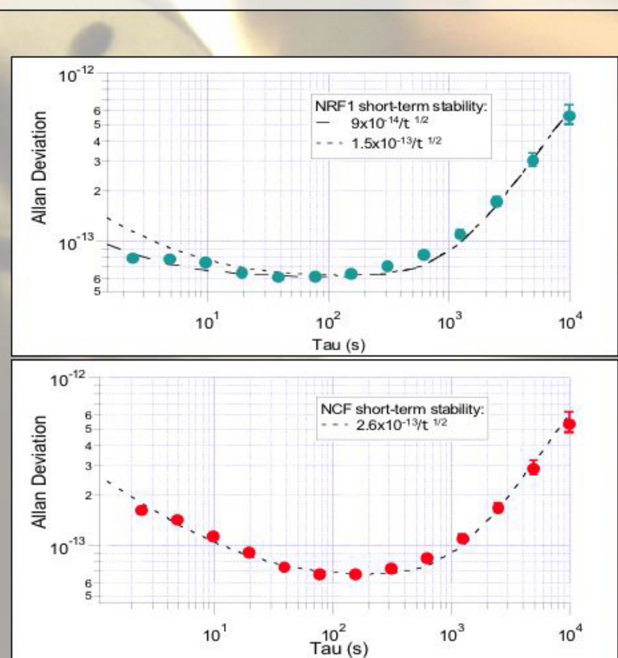
Our fountain versus maser comparisons typically are limited by maser frequency fluctuations in the mid to low 10^{-15}'s. In order to get a better characterization of NRF1 at these levels of stability, we carried out a comparison between NRF1 and our cesium fountain.





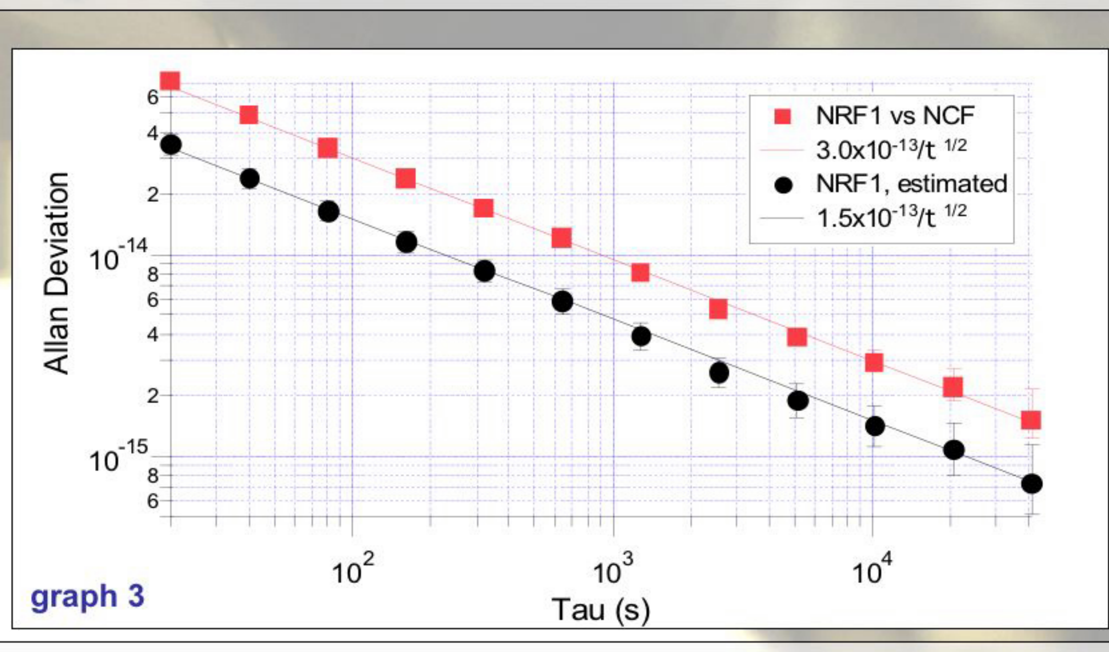
The standard method for determining the short-term performance is to compare the fountain to a maser by phase-locking our crystal to the maser. NRF1 shows performance as good as $1.35\times10^{-13}/\tau^{1/2}$. Deviations from white-frequency noise typically arise when the maser fluctuations dominate the frequency stability comparison





Fitting the Allan deviation plots to the sum of white-frequency (fountain), flicker (crystal), and frequency drift (crystal) noise terms enables us to extract short-term fountain stabilities when the crystal is not locked to the maser.

To measure medium-term performance, we compare NRF1 to NCF. Each fountain measures the frequency of the same crystal and produces (via an AOG synthesizer) a steered output. Measuring the relative stability of these steered outputs produces a comparison of NRF1 and NCF stabilities.



Measuring the relative stability of the rubidium and cesium fountains indicates $1/\tau^{1/2}$ averaging behavior out to τ = 11 hours (for a 3 day run). Coupled with measured short-term stabilities, this allows us to estimate the NRF1, which is consistent with an Allan deviation of 7×10^{-16} at 11 hours.